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China Motorization Trends

New Directions for Crowded Cities

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Abstract: This paper examines two major emerging constraints on transport in fast-growing Chinese urban cities: oil supply and urban infrastructure. The research considers automobile technology, alternative fuels, and mobility choices, as well as policy measures that could be adopted to reduce the use of oil for transport and greenhouse gas emissions. Three transport energy scenarios, "Road Ahead," "Oil Saved," and "Integrated Transport," illustrate potential motorization trends given different policy, vehicle technology, alternative fuels, and driving-behavior assumptions. In the Integrated Transport scenario, where congestion and space constraints favor small and vehicles moving at slower speeds, gasoline and electric cars are the highest in use. Oil consumption in the Integrated Transport scenario is only 12 percent of its value in Road Ahead by 2020, while carbon emission is 79 percent lower. Policies such as vehicle technology and fuel requirements, while important, are not as crucial as integrated land use development, taxation of vehicle use, road pricing, and the prioritization of public and non-motorized transport that could trigger a world of fewer, smaller and more efficient cars. According to experiences around the world, fuel and carbon dioxide (CO_2) concerns alone are not strong enough to promote a change in the path of individual motorization.

Keywords: Transport, Land Use, China, Motorization

1 Introduction

As the fastest growing economy in the world, China is experiencing a rapid increase in motor vehicle ownership, which has led to rising congestion levels, increased air pollution from motor vehicles, increased oil consumption, and a high traffic fatality rate. Although only 10 percent of current trips in Chinese cities are made by car, the rapid growth of private vehicle ownership and use threatens the sustainability of existing transport systems.

Rapid motorization in China is concentrated in its top 20 largest cities by population and economic growth. Most new vehicles are appearing in and around cities because that is where private purchasing power, automobile dealers, maintenance services, and the best transport infrastructure are. China's cities have expanded to make room for cars, but congestion levels have

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spiraled upward and average speeds downward. Given the constraints imposed by very high population densities and limits on the amount of land available for residential and commercial development, as well as strict protections on agricultural land around cities, it seems unlikely that cities can physically expand as rapidly as motorization increases.

Policies targeted at energy use and carbon dioxide (CO_2) emissions could have a modest impact on future fuel use, which is driven by rapid motorization. Trends of private car use and oil demand place enormous strains on urban infrastructure and energy imports. These strains would be mitigated by enacting sustainable transport policies now rather than one or two decades in the future. More fundamental constraints, such as the lack of space, place a more formidable restriction on automobile use and ownership. Strong urban transport policies that prioritize overall mobility over individual ownership and use of automobiles, and seek to maximize the flow of people rather than cars, could have very strong restraining impacts on rising energy use, yet still leave room for the type of small cars best suited for city driving in urban China.

This paper uses alternative personal mobility scenarios developed in a previous study (Ng and Schipper 2005) to illustrate how different policy options could affect vehicle use, as well as how advanced and alternative-fuel vehicle technologies could improve energy efficiency and reduce CO_2 emissions.

2 Transport Trends And Challenges In China

2.1 The Rise of the Transport Sector

Today, human travel by motorized modes in China is still dominated by public transport, which carries approximately 50 percent of all urban trips in China, with bicycling and walking accounting for another 40 percent (Schipper and Ng 2005). The average resident of China travels about 1000 km/year, compared with averages of 15 000 km/year for Europeans and over 24 000 km/year for Americans. Average distance traveled for residents in larger Chinese cities is closer to 5000 km/year, but still well below the levels seen in developed countries. Although mobility in China, measured in annual personal travel, still has a long way to grow, increases in travel distance do not always imply net social benefits, as the benefits of private motorization could be outweighed by its high social costs (Academies 2003).

In 2007, there were approximately 122 million privately owned motor vehicles in China, excluding two-wheeled vehicles and rural vehicles (Xinhua News Agency 2008). The total number of passenger automobiles (with nine or fewer seats), including private and state-owned vehicles, was approximately 12 million or nine cars per 1000 people, far below the global average (He *et al.* 2005). These numbers are still considered very low, as there are over 740 cars (including personal vans, light trucks and SUVs) per 1000 people in the United States, 400 in Japan, 350–500 in Europe, and 150–200 in middle-income countries. However, the motorization of China is set to change significantly as private car ownership continues to increase over the next two decades. National passenger car sales increased by 77 percent from 2002 to 2003, and passenger car production increased by 86 percent during the same period (China Automotive Technology and Research Center (CATARC) 2004).

Figure 1 portrays motorization in relation to income, measured in U.S. dollars using purchasing power parity. On a per capita basis, China's motorization in 2007 was roughly equivalent to that of the United States in the early 1920s, though China's per capita GDP in 2007 was less than the U.S. level of that time. The last dozen points for China in Figure 1 (bottom left, i.e., the most recent years or highest per capita GDP) are very close to the first dozen points for Korea (from the 1960s and early 1970s), which fall somewhere between those of Germany and Japan.

Rapid growth in motorization is bringing both costs and benefits to Chinese societies (Schipper and Ng 2005). Benefits include economic growth due to better accessibility for commercial, public, and private transport, and improved social welfare as a result of increased flexibility and mobility. On the other hand, the negative social costs relate to energy consumption and security, environmental and health impacts, congestion, and traffic fatalities. A looming cost is that of urban migration to allow more space for roads, parking lots, and other transport infrastructure and facilities.

Counting the number of cars in China is not simple, as the problem is not well-defined. The early Chinese definition of "private passenger vehicles" was inappropriate, as it included all private buses but excluded numerous state-owned "cars." In this paper, a car is defined as a four-wheeled passenger vehicle, whether owned by a private individual, a company, or the government (excluding the military). Commercial vans and light trucks are excluded, but not non-commercial SUVs. Tens of millions of rural farm vehicles and motorized two-wheeled vehicles are also excluded, although the former are often spotted in cities (Sperling and Lin 2005). By this definition, the data in Figure 1 suggest China was only at the beginning of its motorization path in 2003, but things are changing rapidly.

The question facing China is what happens if car ownership and use continue to rise more rapidly than GDP for more than a decade. If China continues to follow the trend of motorization growth due to economic development, as already seen in other countries such as the United States and Japan, car ownership could exceed 100 million in China in the next 10 to 15 years. It took 48 years for the first million automobiles to appear in Beijing in 1997, but only six years for the second million, and the number of automobiles in the city passed three million in 2007. According to the China Development Research Center of the State Council (DRC), this rising motorization trend is likely to continue for another 20 to 30 years, yet the current relatively low number of automobiles is deceptive because of the concentration of cars in cities.

2.2 Congestion and Parking

Rapid motorization and automobile concentration have gradually become problems in urban areas. Most of these cities are poorly equipped in terms of infrastructure, such as road capacity, to meet the demands of modern Chinese traffic, although many are in the process of aggressively expanding their road systems. The problem is worsening, in large part due to the increase in total transport demand and to rapid shifts in the modal mix toward larger numbers of individual vehicles. The challenge is to provide more road space that can allow more motor vehicles and other road users to be accommodated in conjunction with appropriate mitigation measures that go beyond road construction.

By the late 1990s, many city governments had started to respond to motor vehicle congestion by expanding existing lanes and building more roads. It is estimated that 42 percent of roadways are in congested situations in the Shanghai Central Puxi area during peak hours. From 2002 to 2003, total road length in Shanghai only increased by 2.6 percent (from 10 191 km to

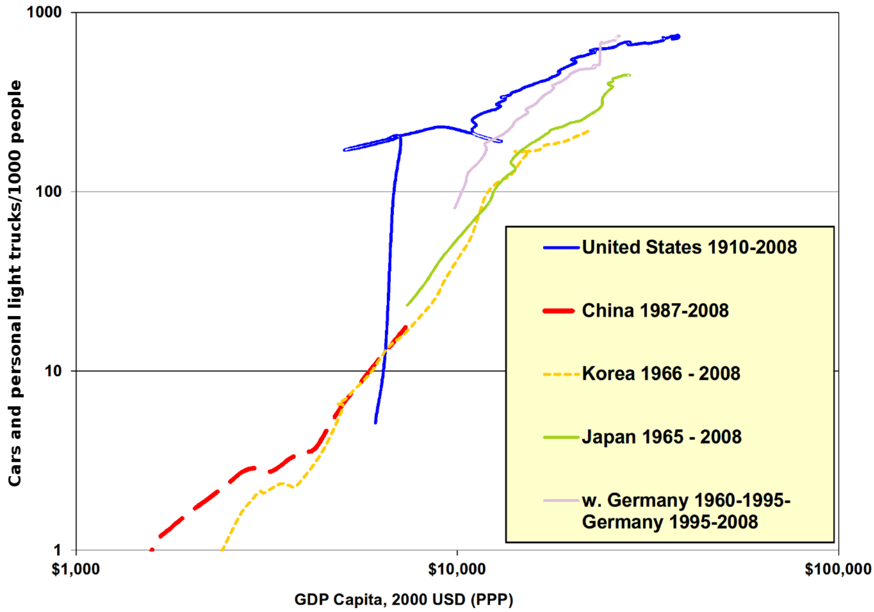

Figure 1: Comparison of car/light truck ownership in U.S., China, Korea, Japan, and Germany

The horizontal axis shows per capita GDP converted to $US at purchasing power parity (PPP). The range of years for each country covered by this GDP range is shown in the legend. The line for the US overlaps itself during the depression years when both GDP/capita and car ownership fell.
Sources: US Federal Highway Administration (various years), National Statistical Abstracts and Transportation year books for vehicles from China, Japan, German (and West Germany) and Korea, OECD (for PPP conversions, GDP and population data).

10 451 km), while the city's total road surface area increased by eight percent (from 15 286 km^2 to 16 510 km^2). During the same period, the total number of motor vehicles increased by 23.9 percent, leading to a reduction in relative road length per vehicle. Not surprisingly, Shanghai is becoming increasingly congested, with an average travel speed of less than 20 km/h on almost 74 percent of 21 surveyed roadways, and less than 15 km/h on 29 percent of surveyed roads. The lowest recorded average travel speed was nine km/h. The average speed traveled on major roadways in the Shanghai city center during peak hours ranged from 10 to 18 km/hour (all figures from Shanghai Metropolitan Multi-Transport Planning Research Center 2004). Such congestion problems are not unique to Shanghai.

Other measures of the potential for congestion include the ratio of road space to vehicles and road space per capita. Table 1 shows urban road densities in Chinese cities. Research by Mao (2003) suggested an average of 7.4 m^2 per capita of road area in China in 1999–2000. Relative to population and population density, these cities do not have enough road space to support significantly higher levels of motorization. Mao also noted that the number of vehicles is increasing faster than the length or area of roads in most Chinese cities. Data from 2000 and 2006 (Table 1) show that although the amount of road space per capita has increased in major Chinese cities, road space per private car has dropped significantly. By comparison, Mao found that London, Tokyo, and New York City had more road length and road length per capita. In 2000, almost 25 percent of the total area of New York City was used as road space, compared to 11.4 percent of Beijing. Both New York and London had more than 25 m^2 per capita of

Table 1: Cities, cars, and road space in 2000 and 2006

City	Year	Private Cars (million)	Road Length (km)	Paved Road Area per Capita	Road Space per Private Car
Beijing	2000	0.49	3624	3.7	85
	2006	1.81	5866	7.4	54
Tianjin	2000	0.21	3608	6.1	200
	2006	0.55	5991	13.98	145
Shanghai	2000	0.05	6641	7.2	1607
	2006	0.51	14619	11.84	422
Chongquing	2000	0.06	2693	2.4	438
	2006	0.28	4011	8.14	243
Guangzhou	2000	0.22	2053	8.16	125
	2006	0.62	5208	13.85	140
Xi'an	2000	0.07*	975*	5.14**	134
	2006	0.26	1480	8.55	125
Average	2000	—	—	5.45	431
	2006	—	—	10.63	188

Data Source: 2001 and 2007 China Statistical Year Book; data are 2000 and 2006 year-end data.
* Authors' estimation based on number of civilian (non-military) passenger cars.
** 1999 year-end data, from 2000 Xi'an Statistical Year Book.

road space, while Beijing had 3.7 m^2 per capita and Guangzhou had a higher number of 8.2 m^2 per capita. Interestingly, only in Guangzhou did road area grow faster than the number of cars. Increased car use and the mixing of cars with bicycles are slowing down other transport modes, particularly buses. This further encourages people who can afford to own cars or two-wheeled vehicles to turn to private motorization, while people who cannot afford car ownership switch to taxis, minibuses, or bicycles. Car owners are not constrained by bus or rail routes. As the price of cars decreases, private automobile ownership becomes more attractive in cities. To some extent, however, the attractiveness of car ownership still depends on congestion and parking conditions in a city.

It is clear that Chinese cities are constrained by the availability of land and there is not much room for road infrastructure expansion, unless the cities continue the current pattern of outward expansion—a phenomenon occurring across the Chinese urban landscape and that may pose a host of long-term challenges. Older neighborhoods where the principal form of housing is three- and four-story apartment buildings could be replaced by high-rise apartment developments that now dominate the skylines of China's largest cities. Such a redistribution of land use could free up area for roads, shops, open spaces, transit hubs, business districts, and more residential units. However, such land use changes could create more congestion, especially if appropriate urban development measures are not in place.

2.3 Land Use and Urban Space

Economic growth and rising incomes are major factors affecting both urban land development and motorization. In addition, land use and management policies in China have changed significantly over the past two decades, mainly due to the implementation of dramatic economic reforms. Land use changes following the transition from a planned society to a market-oriented economy have affected transportation in several ways. The goal to create economic openness and engage China to the rest of the world started in 1978 and resulted in immense economic growth and investment, as the government, which has encouraged private development of state-owned land, is no longer the sole urban developer.

The combination of economic growth and urban development in China has resulted in significant urban land expansion and the loss of arable land in the past decade. In the Beijing, Tianjin, and Hebei regions, the amount of urbanized land increased rapidly throughout the 1990s, particularly in the early part of the decade (Tan *et al.* 2005). The amount of urbanized land in Beijing has tripled in the last two decades (Liu and Prieler 2002), possibly due to increased housing demand and the need for more space for urban activities. About 21 percent of an estimated 6.79 million hectares of cultivated land was converted and used for construction projects carried out by states and collectives from 1986 to 1995 (Lin and Ho 2003). The power of institutional changes to influence land policy decisions—and, subsequently, land uses—has clearly distinguished China from many other countries (Lin and Ho 2003). This could also be due to the transition of the political economy since 1978, from authoritarianism to local corporatism and from plan to market, which has created a new institutional structure for changes in land use and other policies in China.

Land-use changes have considerable impacts on motorization patterns, partly due to changes in population density, and the location of different land uses (Yang and Gakenheimer 2007). For example, the spatial separation between workplace and residence has increased due to housing relocation in Beijing; according to one analysis, this has increased commuting time by 30 percent from the baseline prior relocation and driven an increase in the trip share of motorized modes from 25 to 41 percent of all trips (Yang 2006). Households and manufacturing firms are relocating from city centers to the edges of urban areas where land for housing and production activities are less expensive. However, the development of transportation options to close the gap between employment and housing locations often lags behind the development of land. Although satellite communities and new development zones that are supposed to be self-sufficient with facilities for working, living, education, shopping, and leisure have been developed near urban areas, their impact on travel time is still uncertain (Yang and Gakenheimer 2007). If transportation and land use are not integrated, current development trends will have significant impacts on individual accessibility and mobility—especially given the ongoing rapid increase in motorization.

2.4 Environmental Pollution from Transport

A major environmental impact related to motorization comes from pollutants produced during the combustion of gasoline or diesel fuel in vehicle engines. Such pollutants include carbon monoxide (CO), ozone (O_3), through its atmospheric precursors, volatile organic compounds (VOCs), nitrogen oxides (NOx), and fine particulate matter (Walsh 2003). Respiratory diseases such as infections, asthma and decreased lung efficiency are common in polluted urban cities (Stares and Liu 1996), in addition to reduction in pulmonary function. These public health impacts will not only lead to losses in individual welfare, they could also inflict substantial economic costs upon the society.

Vehicular emissions make up a high and rising proportion of total urban air pollution, and this phenomenon is increasingly being observed in many Chinese cities, as air pollution from industry and households are gradually declining. Studies have shown that 45–60 percent of NOx emissions and 85 percent of CO emissions are from mobile sources in most Chinese cities (Walsh 2000). It is estimated that by 2010 in Shanghai, vehicular emissions will produce 75 percent of total NOx emissions, 94 percent of total CO emissions, and 98 percent of total hydrocarbon (HC) emissions (Wang and Wu 2004). Even with stricter emissions controls and cleaner fuels, mobile-source pollution is likely to continue rising due to increased use of individual vehicles and longer trip lengths.

Urban air pollution is a critical issue for China because most trips involve considerable time on the street inhaling exhaust fumes directly. For example, activities such as walking to and waiting at bus stops or traveling by bicycle imply much greater exposure than traveling by private car. Because of the high physical density of both people and motor vehicles in Chinese cities, public exposure to direct inhalation of vehicle emissions is high. The scarcity of space simply makes the impact of emissions from vehicles more dangerous to travelers, even if car occupants themselves are exposed to less pollution than other travelers as long as their cars are in good working order.

3 Changes In Transport And Land Use Policies

The government of China has enacted various policies and regulations targeted at improving ambient air quality in urban cities, reducing congestion, and improving transport energy efficiency, while promoting the development of the Chinese automobile industry. The challenge for China is to resolve the tensions between these competing priorities and policies. Six major challenge areas, with their respective relevant and influential policy measures, are highlighted in this section.

3.1 Changing Land Use

Significant changes in land policy began in the late 1980s, when the Bureau of Land Administration was established and assumed control of land policy reform, land allocation and acquisition, monitoring of land development, comprehensive land-use plans, and implementation of land laws (Ding 2003). For example, the Land Administration Law, enacted in 1986, made it possible for private organizations and individuals to lease and develop state-owned land, which catalyzed the development of the land market in China. With access to the land market, developers bid for the rights to convert unused land or land for agricultural uses to construction land that supports industrial, energy, and transport projects, as well as city and real estate development plans. In order to meet the demand of growing urban regions, transport-related infrastructure investment and projects have started to increase significantly.

Land use policies have a direct relationship with motorization growth and vice versa, and can even shape the type of transport behavior pattern mainly because transport is a derived demand. Therefore, it is only required when other activities at different locations generate trips.

After the land reforms in China, physical land use configuration has changed (Yang and Gakenheimer 2007), leading to changes in land use density, land use mix, spatial separation of living, commercial and business activities, and the allocation of land for different transportation modes, therefore, affecting transport in China.

3.2 Battling Congestion

Rising vehicle congestion and slower travel speeds are the most obvious impact of rapid motorization. The most immediate response to this problem for most governments is to construct more roads and transport infrastructure. However, additional road capacity will only reduce congestion problems to a certain extent; latent demand will fill the spaces freed, and trip the length and frequency of trips often increases when road supply increases. Above all, congestion is the result of uneven utilization of road space, and building more roads to increase capacity for a few peak hours may be very costly. Alternative measures must be considered.

One approach is to limit ownership of motor vehicles. Shanghai, concerned about usage as well as the lack of parking space, discouraged vehicle ownership for many years by restricting the number of car registrations to 5000 per month (now 6000), and by imposing high taxes on new cars. Even accounting for the fact that some vehicles used in Shanghai are registered in other regions, Shanghai's very low number of cars relative to its GDP or personal disposable income suggests this strategy has a significant impact. The danger of limiting motor vehicle ownership—borne out by the experience of wealthy countries with high car acquisition taxes, such as Denmark—is that the policy will lead to a lower rate of car ownership but higher car utilization. In short, restricting car ownership has a limited impact if the cost of using those cars is low.

Charging for scarce road space seems to be an important strategy for Chinese cities. Pricing schemes may resemble the system designed for Singapore, where every vehicle is charged electronically for entry and use of roads within the congested zone, depending on the time of day (Shanghai Metropolitan Multi-Transport Planning Research Center 2004). Road pricing is usually implemented by public or private highway agencies or by local authorities as part of transportation project funding or transportation demand management programs.

3.3 Encouraging Public Transport

Comprehensive public transport networks have to be established to provide affordable and efficient access, serving as good transport alternatives for potential private car drivers. According to the 2004 National Energy Policy, public transportation (buses and taxis) should be the main access modes in big cities, with rail transportation supporting the transport network, with personal cars and bicycles serving as supplements. For medium-sized and small cities, the National Energy Policy encourages the development of public transportation systems (predominantly buses) while supporting the use of personal cars. Well-constructed transport systems exist in the major Chinese cities, built upon buses, underground rail, and local rail services extended to suburbs.

An innovative public transport system seen in several Chinese cities is the bus rapid transit (BRT) system. First widely adopted in Latin America, BRT is emerging in China as a way to combine the advantages of other transport modes, while holding down costs (Lloyd 2004). BRT systems are often more efficient than traditional bus services, mainly because of their high capacity, operation on segregated bus lanes, rapid boarding and alighting characteristics, transit prioritization at intersections, and modal integration at bus stations and terminals. Such characteristics appeal to passengers, and will aid in achieving sustainable urban transportation in high-population-density urban cities by reducing congestion and vehicular emissions and by providing a cost-effective alternative transport mode. Cities such as Beijing, Changzhou, Chongqing, Dalian, Hangzhou, Chongqing, Jinan, and Xiamen have already embraced the BRT concept of having segregated busways and their associated technologies (ITDP 2010) and have invested in operating BRT systems that are integrated in various parts of their transportation networks. While cities such as Kunming, Shanghai, Xi'an, Chengdu, Tianjin,,and Shenyang are all either already in the process of developing BRT systems, planning BRT designs, or awaiting approval for their BRT proposals.

4 Future Motorization And Motor Vehicle Use Scenarios

In order to better illustrate the possible future development of China's transport sector, three scenarios were developed with different transport assumptions in areas of the number of cars, average trip length, vehicle characteristics, and vehicle technology. Changes in land use planning, including space constraints, were also considered. The scenarios were constructed in a bottom-up fashion, in part using parameters and extrapolations based on experiences in Japan and the Republic of Korea. Each scenario is accompanied by a discussion of policies that could plausibly lead to the outcomes described. Details of the model were previously published in Schipper *et al.* (2000).

The main input assumptions for the scenarios are shown in Table 4. However, fuel taxes, vehicle use fees, and other policies are not quantitative data and are simply used as qualitative measures to trigger the other input assumptions in the scenarios. These outcomes are not predictions, but by setting up three possible futures, they can provide a picture of the potential impact of various technologies and other options that could significantly affect personal automobiles and their use.

The "Road Ahead" (baseline) scenario assumes the current growth rate of motorization continues. Vehicle technology is dominated by conventional gasoline engines, car use is not restricted and no significant fuel taxes are implemented through 2020. The "Oil Saved" scenario is driven by a clear motivation to save oil, backed by phasing-in of fuel taxes until they reach the level of those in Japan in early 2005, at approximately \$0.70/liter (International Energy Agency 2005). The third scenario is based on an integrated transport approach that assumes thoughtful land use, pricing, and transit policies as well as successful prevention of serious traffic congestion and the preservation of vibrant cities where non-motorized transport remains a viable option for short trips and fast collective transport provides good service for longer distances. In this scenario, small and efficient vehicles will play a considerable role in reducing fuel consumption, as will the construction of efficient transit networks.

Table 2: Transport and technology scenario assumptions.

Scenarios/Assumptions	Road Ahead (Baseline)	Oil Saved	Integrated Transport: Space Saver
GDP and Population	GDP projected to increase at 6 percent annually		
Motorization Rate of Increase	China reaches the car/GDP ratio that Korea had in the mid 1990s by 2020.	With higher oil prices and taxes, the number of cars in 2020 is 10 percent lower than it is in "Road Ahead."	With space being a severe constraint in Chinese cities and the implementation of parking charges, fees and taxes, the number of cars in 2020 is 50 percent less than in "Road Ahead."
Total Number of Cars In 2020 (Thousands)	145,733	131,159	72,866
Car Characteristics (Weight)	Average weight falls to 1200kg.	Average weight falls to 1,200kg and power is lower than in "Road Ahead."	Average weight falls to less than 1,000kg as mini-cars become popular, mainly to save space.
Car Utilization – Distance Traveled (km/vehicle/year)	2010: 14,496 2020: 12,484	2010: 13,466 2020: 10,238	2010: 12,948 2020: 8,775
Fuel Choices	Almost all cars run on oil, with 1 percent of total motor vehicle fleet based on CNG in 2015 and 2 percent in 2020.	20 percent of motor vehicles use conventional gasoline. 15 percent of vehicle share are HEVs in 2010 and 50 percent in 2020. 10 percent of vehicles are CNG in 2010, 20 percent in 2020, and 10 percent are electric in 2020.	In 2020, 30 percent of total motor vehicles are gasoline vehicles, of which 15 percent are small vehicles. Market penetration of HEVs is 25 percent, small electric cars 25 percent, and CNG cars 20 percent.
Assumptions made but not quantified in the scenarios			
Fuel Taxes (Crude oil price in 2005 assumed to be approximately US$50 (2005) per barrel)	US level of taxation, i.e. approximately US$0.20 (2005) per liter.	Japanese/European level of taxation, i.e. approximately US$0.70 (2005) per liter.	Japanese/European level of taxation, i.e. approximately US$0.70 (2005) per liter.
Vehicle Use Fees	None	None	Significant charges on vehicle use in cities such as road pricing and parking charges.

Scenarios/Assumptions	Road Ahead (Baseline)	Oil Saved	Integrated Transport: Space Saver
Integrated Land Use Planning	Cites manage to expand in no particularly planned way, with cars the way to "connect" separate parts of regions, despite slow travel times	Higher fuel prices and fuel economy standards have no major impact on changing land use.	Land use policy that integrates transport demands with urban development, strongly encouraging compact cities with transit networks and housing, jobs, and services clustered around rapid transit, e.g., rail or BRT. Growth boundaries rein in endless expansion of urban areas
Other Policies	None	Encouragement of alternatives to traditional gasoline cars, i.e., hybrids, CNG, mini cars.	Urban transport policies actively promoting the use of public transportation systems. Higher urban densities and higher parking prices tip vehicle selection towards very small cars.

4.1 Scenario Results

Energy use in each scenario is broken down by vehicle and fuel type in Figure 2. Compared to "Road Ahead," energy use is 38 percent lower by 2010 and 78 percent lower by 2020 in the "Integrated Transport" scenario. Total 2020 oil use in "Oil Saved" is approximately 55 percent less than in "Road Ahead," but is still more than two times higher than oil use in "Integrated Transport." Additionally, the total oil consumed in 2020 in the "Integrated Transport" scenario is only marginally higher than in 2003. This distinction shows how transport policies can indirectly lead to huge oil savings and energy security consequently. In "Integrated Transport," oil use is a mere 300 thousand barrels per day (kbpd) by 2020, 12 percent of the amount consumed in "Road Ahead."

Using our input assumptions, we estimated 2003 carbon emissions from cars in China at around 8.8 million tonnes of carbon (MtC). Emissions will grow to 20 MtC in 2010 and 102 MtC in 2020 in "Road Ahead," assuming no additional policies other than existing fuel economy regulations are implemented (Figure 3). For comparison, the International Energy Agency predicts that China's transport-related CO_2 emissions will reach 162 MtC by 2020, up from 67 MtC in 2002 (Schipper *et al.* 2002).

In the Integrated Transport scenario, the total number of cars is limited to approximately 50 percent of the total number achieved under the Road Ahead scenario in 2020 due to congestion, parking and access difficulties, integrated land use development and policies, the taxation of fuel at European levels, and different transport policies. Similarly, distance traveled per car

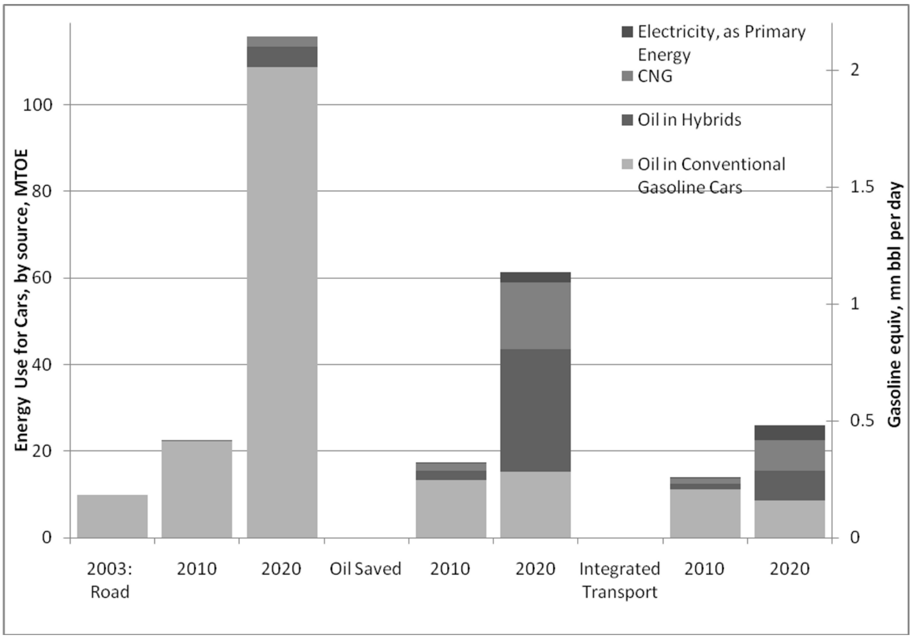

Figure 2: Energy use for cars, by fuel and propulsion

Primary energy required for electricity generation and transmission is included, but no primary adjustments were made for production, transmission, or distribution of gasoline or CNG. 2003: Road refers to the "Road Ahead" scenario.

plummets to 8775 km per year by 2020 (Table 4) because of the high costs of driving, and the options of good public transport systems.

5 Policy Options

China already has a strong set of policy measures that can help ensure the nation's energy security while protecting air quality and other goals (Ng and Schipper 2005). This study proposes additional options that will have an impact on vehicle ownership, vehicle use, infrastructure use, infrastructure access, road space use, and fuel demand, leading to increased energy efficiency, increased mobility, and reduced transport emissions. Most of these policies are implied in the assumptions underlying the scenarios discussed above, and their impacts are reflected in the scenario results. Despite the importance of technology advancements and standards, land use planning will continue to play a crucial role in shaping future travel patterns and transport emissions.

5.1 Alternative Fuel Requirements

Fuels other than gasoline and diesel have already been used in the Chinese transport sector. If urban transport constraints limit the size of overall fuel demand, then alternatives to petroleum-based fuels can provide a significant fraction of the total needed. This is because the number of cars, and therefore the fueling infrastructure itself, is relatively small. By contrast, in virtually every other country, alternatives have only succeeded when they were very cheap, such as liq-

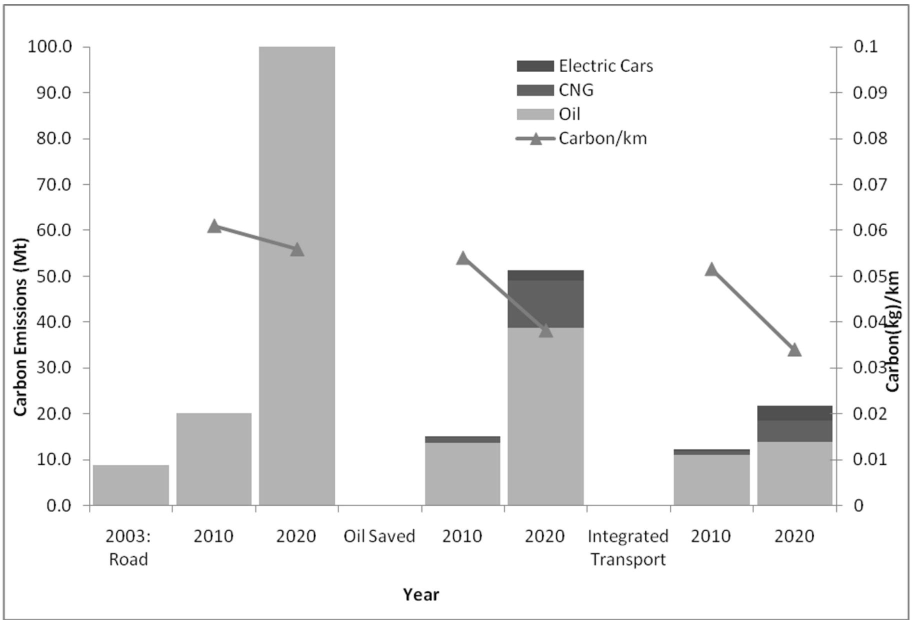

Figure 3: Carbon emissions from motor vehicles of different technologies by fuel

2003: Road refers to the Road Ahead scenario.

uefied petroleum gas (LPG) in Italy and the Netherlands (Schipper *et al.* 2002). China has no such options on the scale likely required. Options for China include methanol, hydrogen fuel cells, or liquids from coal, undoubtedly an expensive and environmentally difficult option (Ni *et al.* 2008).

The two alternative transport energy sources considered in the scenarios and discussed in this study are compressed natural gas (CNG) and electricity. It is likely that the use of natural gas for transportation will continue to increase in order to meet the growing need for clean transport fuel. Natural gas is now used in approximately 110 000 vehicles (mostly buses and taxis) in 12 Chinese cities (Agency) 2004). This fuel is, however, constrained by the supply of natural gas and by the fact that it is more difficult to transport than oil. Therefore, despite CNG being a relatively clean fuel, vehicles using it might be limited to a smaller role in the transport sector but should be used in public vehicles in polluted urban areas.

Electricity is another potentially clean transport energy source with minimal emissions impact. Small electric vehicles are effective compared with gasoline vehicles when used for short travel distances at cold start or in bad traffic, two factors that increase fuel consumption in conventional vehicles. However, China's electric power system is based predominantly on coal. An analysis of electric bicycles (Cherry and Weinert 2007) suggests that small electric bicycles have a modest advantage over conventional gasoline-powered mopeds or motorcycles. By implication, small electric cars would probably have lower overall CO_2 emissions and primary energy consumption than conventional gasoline automobiles more because they are small than because they are electric. Considering the space constraints China is experiencing, as noted earlier, passenger automobiles will not be able to move rapidly or travel far in the kind of traffic seen even today. It is this constraint imposed by land and land use—not just energy—that may make small electric cars more popular than larger cars as an extension of the present popularity of e-bikes over more powerful mopeds and motorcycles. If electric vehicles do emerge as a major mode of individual transport, the aforementioned factors must be evaluated to judge their overall impact on the environment.

Small electric bicycles have proven their worth as a transition from pedal bicycles and as alternatives to polluting motorcycles. With zero tailpipe emissions, they do not contribute to local air pollution (particularly carbon monoxide) or to noise on crowded routes. Such electric vehicles can also be recharged at home, reducing the need for commercial filling stations in densely populated areas so long as secure parking and recharging areas are developed within residential units. Electric bicycles travel at lower speeds than cars and may provide a safe alternative to the higher speeds that prove fatal when motor vehicles collide with pedestrians. Another benefit of the development of the electric bicycle market is that they may divert interest from car ownership, providing enough time for authorities to construct more space-efficient transport networks and infrastructure. This, in turn, could lead to the adoption of electric mini-cars or fueled mini-cars or even plug-in hybrids that provide modest speed and comfort for individual transportation without the need of an immense road network built for higher speeds and greater fuel use vehicles. But the final impact analysis must account for the source of electricity and the disposal of the batteries once they can no longer be used, and determine if electronic bicycles can substitute for cars, buses, and walking, or complement these modes.

5.2 Motor Vehicle Taxation

When integrated into transport policies, taxation can efficiently manage transport demand, as it encourages mode shifts and may be a good source of revenue. Current taxes applicable to motor vehicles in China include value added, excise, vehicle acquisition, and vehicle usage taxes (Huang 2005). The vehicle usage tax in China is collected on an annual basis and the amount of tax paid depends on the type of vehicle. An annual tax offers more flexibility than a sales tax, as tax rates can be altered over time and the burden is distributed over a longer time period for vehicle owners (Schwaab and Thielmann 2002).

Different features might be incorporated into vehicle taxation according to different transport strategies. For instance, taxation could be implemented by vehicle type, vehicle price, vehicle size, emissions, and noise levels. Differentiated systems, as applied in Sweden and Germany, offer incentives for vehicle owners to switch to low emission vehicles (Breithaupt 2002; International Energy Agency 2000). This is often the case when vehicle taxation is differentiated according to specific emission standards, with higher taxes on vehicles that emit more pollutants. Vehicle manufacturers might also be encouraged to develop less-polluting vehicles that would appeal to consumers due to their lower vehicle tax classification (Carruthers 2002). However, it is important to note that vehicle taxation, unlike other taxation options, does not influence the variable costs of transportation and therefore is unlikely to influence vehicle distance traveled or other driving habits. Vehicle taxes would be the highest in the "Integrated Transport" scenario, as authorities seek to reduce congestion and private motorization demand by increasing vehicle costs.

5.3 Fuel Taxation

Using fuel taxation as a policy instrument can recover the variable costs of driving by charging vehicle users for transport infrastructure indirectly through individual use. Since fuel is one of the largest and most visible variable costs of vehicle use, fuel taxes encourage drivers to make more efficient use of their vehicles, reduce trip frequencies, and even switch to more fuel-efficient vehicles.

The level of fuel taxes imposed should be enough to cover the public costs of vehicle emissions and provide revenue for transport infrastructure construction and maintenance (absent direct road pricing schemes). The revenues collected from transport fuel are usually allocated for transport purposes, as seen in many other countries with developed, transitional, and developing economies (Carruthers 2002). Fuel prices should include taxes to reflect the externalities and risks of foreign oil imports and the environmental damages related to fuel quality.

If fuel prices continue to remain low in China, energy consumption and emissions from the transport sector could follow the projections in the "Road Ahead" scenario. If China wants to reduce its energy consumption to levels projected in the "Oil Saved" and "Integrated Transport" scenarios, Japanese-equivalent fuel tax rates should be implemented in order to encourage individual consumers to use less petroleum. An increase in fuel taxes will strengthen the market for advanced vehicles and alternative fuel vehicle technologies.

5.4 Congestion Pricing and other Variable Charges

Road pricing is another demand management strategy through which drivers pay directly for utilizing public services. Some examples are toll roads, toll bridges, and congestion pricing systems, whereby drivers are charged when entering specific zones during certain time periods. Revenue collected can be used to cover the costs of building and maintaining transport infrastructure, including alternatives to cars. These approaches can reduce overall vehicle use and shift some travel to less-congested times or places. Since car fuel use rises with congestion, congestion-reduction measures tend to slightly improve fuel efficiency. While this implies that higher fuel taxes will have a greater impact in congested areas, these are not the most appropriate ways to charge for scarce road space.

Charging for road space is an important strategy for Chinese cities, where central areas have as little as one-fifth of the space per capita compared with even more congested cities such as London, Paris, or New York. The Shanghai Metropolitan Transport White Paper (Shanghai Metropolitan Multi-Transport Planning Research Center 2004) discusses electronic road pricing (ERP), which is a model that Singapore has followed in its general transport strategy for the past two decades (Menon 2000), as have London and Stockholm more recently. For China, a pricing scheme could be sophisticated, with vehicles charged on a per-kilometer basis and rates varying according to the day of the week, time of day, the type and size of vehicle, congestion level, and the road and place of entry.

Parking charges should reflect the true cost of parking and be used as a measure to efficiently allocate parking spaces. Parking is free or priced at a subsidized rate in many countries. However, as a demand-side management measure, the costs of parking facilities or on-street parking should be distributed to motorists. Every motorist should know what it really costs to bring a car into a zone where land space is scarce. Parking charges can create substantial revenues for local municipalities and can be used for transport infrastructure maintenance. The implementation of parking fees will increase the cost of driving in urban areas, which will make private car use less appealing. For China, this will certainly influence future patterns of car use, cruising behavior, and congestion, and thereby decrease emissions. Raising parking fees to reflect the real costs and value of space, while enforcing existing parking rules, will discourage the use of cars in congested zones.

Road pricing policies and other measures to increase the variable costs of driving are extremely important in the "Integrated Transport" scenario, where congestion is largely avoided because of road pricing and other complementary measures to regulate car use. If this scenario is to be realized, it is important to announce and implement pricing policies early, before too much investment in private automobiles and on infrastructure dependent upon private vehicle use is committed.

5.5 Public Transportation and Non-Motorized Transport

An ideal public transport system must be fast, convenient, comfortable, and affordable in order to be an attractive alternative to other transport modes. If mass transit such as conventional buses, fast buses in dedicated corridors, subway trains, and other rail-based systems are to compete with private cars or even motorbikes, their speed and cost must be improved, as an increasing number of Chinese families can afford private motor vehicles. A good public transport system must be available to passengers if private car ownership or use is to be restrained and congestion reduced. Above all, land constraints dictate that public transport systems must be prioritized, since they can move so many more people per hour than private cars. Technical, financial, and operational components must be integrated so as to allow a high-quality system that will incorporate existing forms of transportation.

Underground subway trains tend to be faster and cleaner than street-level transport, but only less costly if subsidized by local or national authorities. Additionally, subway trains can only cover a limited area of a city and total passenger trips, as experience with the most subway-intensive cities, such as Paris, London, New York, and Moscow, suggests. Typically, subways have high fixed costs per unit of distance or per passenger per hour capacity. On the other hand, light-rail and commuter rail provide important links for commuters and shoppers, but still have high investment costs. Traditional buses, which are the backbone of transportation in most Chinese cities, are often caught in road congestion. Yet geography and the population density in Chinese cities ensure that buses will always be the backbone of any public system because they can reach the widest areas. Speeding up buses is the most important and cost-effective way of maintaining an effective public transport system.

The central government should continue to encourage public transport investments, and allow cities to incorporate BRT into existing transport networks. Enhanced national and regional BRT marketing policies could promote a wider use of public transport and BRT, and improve their appeal to the general public. Good alternative transport modes provide options to private car ownership and use, and limit congestion and other impacts of motorization such as pollution.

Non-motorized transport (NMT) users, such as pedestrians and bicyclists, are also more efficient users of scarce road space than users of private motor vehicles, and non-motorized modes are the most efficient and environmentally sustainable when making relatively short trips (Hook 2002). In virtually every other country, however, NMT has yielded to motorized public transport and then to individual motor vehicles. The most notable industrialized countries where NMT retains 20 percent or more share of all trips in urban areas are Denmark and the Netherlands, but the high share of NMT comes principally at the cost of bus travel and short car trips. High fuel taxes, careful urban planning, integrated networks of dedicated bike lanes, and a strong component of local commercial activities keep these alternatives to cars important. Road pricing and stronger urban transport systems are complementary. Raising the cost of using (and parking) cars in congested areas always increases ridership on collective transport.

The government of China could continue to encourage public transport investments to enhance its quality and promote cycling and walking within cities. Good alternative transport modes provide options to private car ownership and use, and will limit congestion and transport pollution. This phenomenon is projected in the "Integrated Transport" scenario, where severe traffic congestion starts to restrict total car utilization and significant charges are added to increase the total cost of driving at the same time. Success depends not simply on building subways or putting buses on the street, but on designing transit facilities that are easy to approach by foot or bicycle, and on supporting transit with land use patterns that concentrate homes, jobs, and shopping near those facilities. The challenge for China is to increase the speed, reliability, and convenience of its public transportation systems before too many individuals choose to use private transport modes.

5.6 Land Use and Urban Development

Integrated urban planning procedures, including detailed regulations for land use, must be established to prevent land-use conflicts or development patterns that could encourage unnecessary motor vehicle growth. In general, transport infrastructure supporting rapid motorization should always be evaluated carefully together with any compensation procedures before any decisions are made. The time lapse between the development of urban areas and the development of transport systems to serve them should also be reduced. An integrated approach to land use and transport development is one factor leading to the reduction of car use and distance traveled in the third scenario, "Integrated Transport." Transportation should also be seen as spatial interaction between different regions with different land use activities. Motorization is one of the many factors affecting urban development. Unfettered expansion of parking facilities, road networks, and other transport infrastructure can lead to market demand for land beyond urban boundaries and ultimately to sprawl.

6 Discussion And Conclusion

The trends and scenarios examined in this study illustrate important choices that Chinese policy makers must confront. Given the rapid motorization in China in recent years, authorities have to act fast in order to avoid concomitant worsening of traffic safety, urban congestion, pollution, and energy problems. It is necessary to develop cleaner, safer, rapid transportation systems that increase access to more people, rather than following the narrower path of rapid individual motorization, as scenes from congested Beijing and other major Chinese cities already suggest. A key issue related to emissions and other problems so far overlooked by Chinese authorities is that many motorization impacts depend not only on the emissions or other per-kilometer impacts of vehicle operation, but on the total distance driven. If present trends in car use continue, the huge increase in distance traveled will increase carbon emissions, local air pollution, and energy consumption significantly, offsetting much of the reduced emissions per kilometer achievable through current regulations.

The scenarios in this paper were produced using an approach first developed in the late 1990s (Ng and Schipper 2005; Schipper *et al.* 2000), when oil markets were weak as a result of the Asian economic crisis. Subsequently, oil prices remained stable until rising in 2002. The exponential growth in car ownership and use in China after 2000 (Ng and Schipper 2005) provoked discussions of rising fuel demand and consequent CO_2 emissions. Yet even in 2008, China's oil use for cars (approximately 450–500,000 barrels per day) and the resulting CO_2 emissions were both insignificant compared to the nation's total consumption, and an even smaller fraction of worldwide oil demand (80 million barrels per day, of which nearly 60 million barrels are for transport). However, if no measures are taken to regulate transport demand and develop vehicle technology, energy use in the transport sector will continue to increase, together with all the other negative motorization impacts. By 2006, oil consumption in China far outstripped domestic production, and at the same time the increase in car ownership through 2007 already exceeded the levels for 2010 in the "Road Ahead" scenario. Our study has also shown that the number of cars is growing much more rapidly than the expansion of road space or road length. Policy measures that will promote sustainable transport development and land use planning must be implemented in a timely manner to reduce the pressure of rapid motorization on Chinese cities.

The use of advanced and alternative-fuel vehicle technologies could reduce the transport externalities related to energy and local emissions while meeting the demand for private car use. Appropriate policy actions will make possible the widespread use of clean, small, and efficient cars, especially if car use is regulated by both restraint policies and the strategic provision of alternative transport modes. However, clean fuels alone will not ultimately solve the transport problems China faces, due to the physical constraint of road space. The solution will have to include technology development together with transport demand management and the provision of diverse public transport networks. Appropriate policy measures that could change travel patterns have to be implemented and enforced as complementary tools.

The "Integrated Transport" scenario was developed using the fundamental assumption that congestion is undesirable and will be contained in the future through innovative land use planning and transit development. Achieving this goal requires the participation of strong-willed stakeholders to develop rapid transit and maintain secure routes for pedestrians, bicycles, and electric bicycles, as well as the motivation to create real disincentives for using private automobiles in crowded and polluted cities. The latter goal will require careful formulation of strategies. Integrated land use development, in which urban development includes accessibility and mobility objectives, is a significant factor in reducing private vehicle use and subsequently energy use and carbon emissions in this scenario. Transport policies should therefore be integrated into urban planning processes, in a timely manner that will allow strong linkages between transport and the locations of employment and residences.

Fuel taxation and congesting pricing play a major role in reducing vehicle use, energy consumption, and carbon emissions in the "Integrated Transport" scenario. Private car users bear the burden of increased taxes and charges, but the potential reductions in driving and congestion benefit the huge majority of pedestrians, cyclists, and bus riders. New parking policies must charge users at a cost that will reflect the scarcity of land. The more revenue is channeled into infrastructure projects, congestion alleviating projects, and alternative transport development, the more the public will accept the imposition of relevant charges.

It is clear that vehicle demand has to be optimally managed and regulated in order to reduce the adverse impacts of transportation.

Our scenarios demonstrate that, given the policy and transport assumptions we have used, trends in motorization in China could be restrained significantly if city authorities understand the fundamental constraint of land scarcity in and around urban areas in China. The fact that road space is losing the race with the ownership of conventional automobiles is the key sign of this constraint. Even today, mini-cars (defined as cars with engine capacities less than 600CC) make up almost a third of new vehicles in Japan, a trend motivated more by concerns about space than by the desire to save fuel. If the same concerns are translated through policies into a different outcome in China than Korea or Japan have experienced to date, the scenario we offer as "Integrated Urban Transport" could be realized. As an important by-product, both China's energy consumption and CO_2 emissions would be reduced by these land constraints, if translated into a new path combining personal mobility (small four wheeled vehicles) with strong collective urban transport policies.

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